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DETERMINATION OF MEAN DROPLET SIZE IN CALCULATING VENTURI TUBE ASH COLLECTOR

A. I. Akburt

Environmental Protection Agency
Research Triangle Park, North Carolina

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DETERMINATION OF MEAN DROPLET SIZE IN CALCULATING VENTURI TUBE ASH COLLECTOR

[Opredeleniye Srednego Razmera Kapel' dlya Rascheta Zoloulovitelya]

by

Engineer A. I. Akburt (graduate student), and Candidate of Technical Sciences L. I. Kropp, Ural of the State Trust for the Organization and Rationalization of Regional Electric Power Plants and Networks [ORGRES] and the All-Union Institute of Heat Engineering imeni F. E. Dzerzhinskiy [VTI]

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In calculating the efficiency of ash collection in Venturi tube ash collectors, one of the determining parameters is the mean droplet size forming in the spraying of scrubbing water. This study deals with an experimental determination of droplet size when the liquid is broken up by a gas stream. The following empirical formula [1-5] is the most reliable for determining the mean size of droplets formed in the atomizing of liquid in a Venturi tube:

$$d_{\text{м}} = \frac{585\sqrt{\sigma}}{v\sqrt{\rho_{\text{г}}}} + 597\left(\frac{\mu_{\text{ж}}}{\sqrt{\sigma\rho_{\text{ж}}}}\right)^{0.45} q^{1.5}, \qquad (1)$$

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(IV)

where u is the difference between the velocities of gas and drops, m/sec; σ is the coefficient of surface tension of the scrubbing liquid; ρ_1 and μ_1 are the density and dynamic viscosity of the liquid, g/cm^3 and g/(cm·sec) [respectively]; and q is the specific consumption of scrubbing liquid, l/m^3.

Formula (1) is based on numerous experiments with pneumatic nozzles using a variety of liquids over a fairly wide range of variation in the physical parameters of the liquid at subsonic gas velocities. If we use water as the scrubbing liquid, then formula (1) takes on a simpler form:

$$D_0 = 4810/u + 28{,}8q^{0.5}. \qquad (2)$$

From formulas (1) and (2) we see that at a low specific water consumption the effect of the second term becomes negligible; the dynamic action of the gas stream on drops is taken into account by the difference between the velocities of gas and drops.

The determination of D_0 as applied to specific operating conditions of ash collectors using Venturi tubes at electric power plants was carried out on a pilot plant installation at the Verkhne Tagil'skaya GRES [State Regional Electric Power Station]. The scope of the study included the determining the disperse composition of droplets in the jet of the UO ORGRES centrifugal nozzle in relation to the pressure of water ahead of it, and also measuring the diameter of droplets in three diffuser cross-sections (directly beyond the throat, in the middle, and at the outlet).

The nozzles were tested according to the scheme shown in Fig. 1. A removable plate remaining fixed as the drum was rotated was placed inside a drum with a slit. On the plate were positioned 30 x 40 mm glass plates coated with a mixture of transformer oil and technical vaseline, and the viscosity of the mixture was chosen at a level so that no noticeable deformation of a drop was observed when it fell on the surface of the plate.

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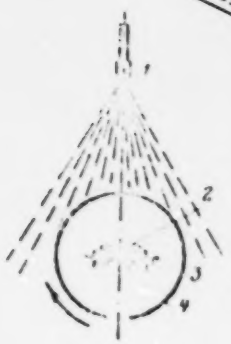

Fig. 1. Stand for nozzle testing:

1 -- nozzle; 2 -- glass plates

3 -- support; 4 -- rotating drum

bearing slit

The nozzle was placed 200 mm from the plate in such a way as to ensure the trapping of drops over the entire diameter of the cross-section of the air cone. In the initial position, the longitudinal slit of the drum was beneath the plates, which prevented droplets falling onto their surface. Collection of droplets is carried out as the drum was rotated by 360° C, when the drum slit was over the surface of the plates (Fig. 1 b). An accessory in the shape of a cross on which were placed test tubes collecting the moisture was used in determining the density of the water spray along its cross-sections.

Experimental data on the disperse composition of droplets in the nozzle spray pattern and the mass distribution of liquid across the water spray cone are shown in Fig. 2.

A device shown in Fig. 3 was used to determine the disperse composition of droplets as they travelled in the gas flow.

In the initial position, the surfaces of the glass plates were protected against droplets falling on them by the wall of the outer hood; sufficient hermeticity was afforded by careful fitting of the rod against

the hood (with a clearance of not more than 40 microns). As the tubing was moved by means of a rod from its initial position to the working position in a specific time interval, regulated with an electronic millisecond timer, access was open to the flow of air bearing droplets into the inner volume of the device. The disperse composition of droplets falling on the plate differed practically not at all from the same composition and the flow, since even for the very small droplets (50 microns in size) Stokes' criterion is quite large and, therefore, the coefficient of inertial deposition is equal to unity. In the three diffuser cross-sections (at the inlet, in the middle, and at the outlet) the droplets for 12 different distances from the axis on eight-ten plates, which were then photographed to determine droplet size. The mean droplet diameter was calculated by the formula

$$D_0 = \sqrt{\frac{D_1^2 n_1 + D_2^2 n_2 + \ldots + D_k^2 n_k}{\Sigma n}} \qquad (3)$$

where D_1, D_2, ..., D_k are the droplet diameters; n_1, n_2, ..., n_k represent the numbers of droplets of specific sizes; and Σn is the total number of droplets.

The results of measurements at two air flow rates in the throat of 60 and 50 m/sec and for a specific water consumption of 0.1 kg/m^3 are given in the table; the mean droplet diameter is 160-190 microns for this flow velocity range and differs little along the diffuser length.

Indirectly this shows that the process of fractionation of droplets by a gas flow is practically culminated in the vicinity of the throat.

When we examine the table data, we must take into account the fact that they were obtained under conditions when the heat transfer from the air to the droplets was low and, therefore, the evaporation of water was

not high. Still, in industrial equipment some of the water in the Venturi tube evaporates, resulting in a smaller true droplet diameter. With reference to the data of tests made of ash collectors using Venturi tubes at electric power stations [6], the experimental values of the mean droplet size at the outlet from the throat was reduced by 10 percent and these revised D_0 values were then used in deriving a formula for calculating the main droplet size.

A	B		
	Section I C	Section II D	Section III E
50	153	156	157
60	178	179	179

KEY: A -- Velocity of gases in Venturi tube throat, m/sec

B — Mean droplet diameter, microns

C -- Section I

D — Section II

E — Section III

These experimental data allow us to derive an expression for determining mean droplet size at the outlets from the throat. By formula (2), when water is used as the scrubbing liquid and when its specific consumption is low, D_0 can be represented as

$$D_0 = C/(w_г - w_d),$$

where C is some constant; $w_г$ and w_d represent the velocities of gases and droplets, m/sec. The coefficient C was determined by using experimental values of D_0 and calculated values for w_d.

Electronic computer calculations made of the velocity of drops employed the method presented in [5] for Venturi tubes of the configuration adopted at electric power stations [6], for three capacities with respect to the gas flow of $50 \cdot 10^3$, $100 \cdot 10^3$, and $200 \cdot 10^3$ m^3/hr, and a mean

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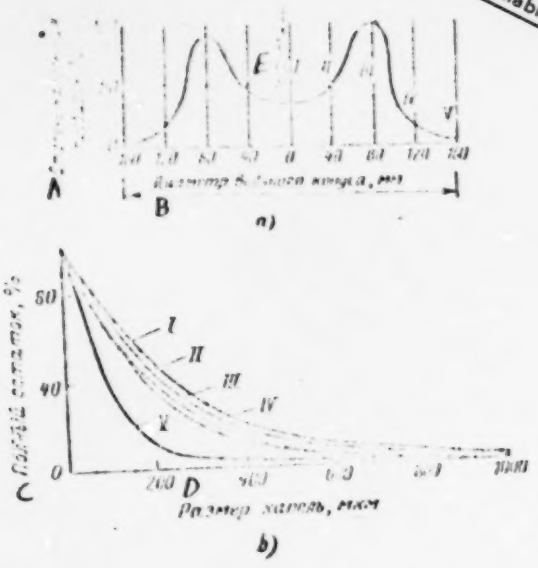

Fig. 2. Data on the distribution of liquid in the water spray pattern (a) and the disperse composition of droplets at sections I-V, beyond the nozzle (b)

KEY: A -- Degree of test tube filling

B -- Diameter of water cone

C -- Total residue

D -- Droplet size, microns

E -- Axis of function

inlet gas temperature of 140° C (neglecting the evaporation of water in the apparatus). For each capacity, the calculation was undertaken for three velocity values of gases in the throat of 40, 60, and 80 m/sec. In all the calculation variants, the velocity of droplets at the outlet from the nozzle was 12 m/sec, and the velocity of gas at the inlet to the convergent area and the outlet from the diffuser was 20 m/sec. The calculations were conducted on the assumption that the droplet diameter was constant over the entire length of the Venturi tube. The droplet velocity was

calculated at 24 cross-sections of each tube type class, including 11 sections for the divergent area, three sections for the throat, and 10 sections for the diffuser. Then the maximum difference between the velocities of gases and drops at the end of the convergent area was calculated, $(w_g - w_d)_{max}$, required in determining the mean droplet size D_0.

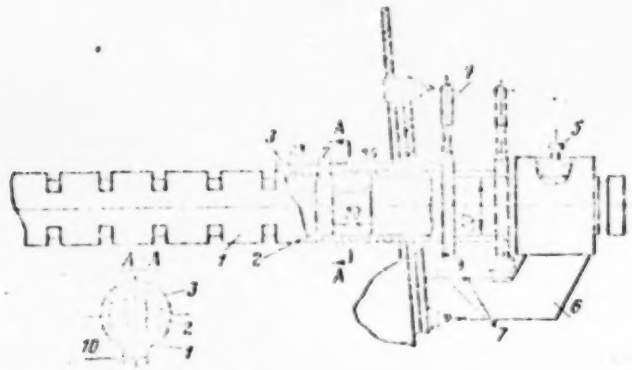

Fig. 3. Device for determining droplet diameter in a gas flow

1 -- outer hood; 2 -- rod; 3 -- 20 x 20 mm glass;

4 -- handle; 5 -- set screw; 6 -- bracket;

7 -- actuating contacts of millisecond timer

Fig. 4 shows the dependence of the difference between the velocities of gases in the throat and droplets at the throat inlet that is the maximum over the Venturi tube length, that is, at the outlet from the divergent area, as a function of the velocity of gases in the throat. From this figure we see that the quantity $(w_g - w_d)_{max}$ rises appreciably with increase in the velocity of gases in the throat, and the intensity of this rise is the same for setups of any capacity. Still, for a given w_g the quantity $(w_g - w_d)_{max}$ decreases slightly with increase in the capacity of the facility.

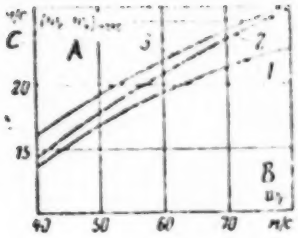

Fig. 4. Dependence of maximum difference between the velocities of gases and droplets on the gas velocity in the throat for Venturi tubes with the following capacities: $50 \cdot 10^3$ (1); $100 \cdot 10^3$ (2), and $200 \cdot 10^3$ m^3/hr (3)

KEY: A -- $(w_g - w_d)_{max}$ C -- m/sec

B -- w_g, m/sec

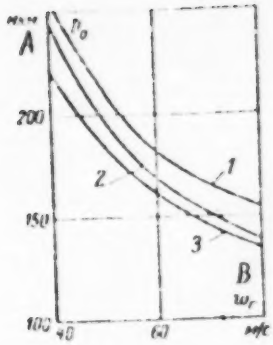

Fig. 5. Dependence of mean droplet diameter on velocity of gases in the throat of a Venturi tube

1-3 -- cf. Fig. 4.

KEY: A -- Microns

B -- w_g, m/sec

Based on these calculated and experimental data, we derive the following formula for calculating the mean droplet diameter D_0:

$$D_0 = 3500/(w_g - w_d)_{max}.$$

When applying this formula, one must remember that it is fairly valid only for Venturi tubes with nozzle spraying. The constant coefficient C = 3500 was obtained, as already noted, with allowance for partial evaporation of water in the Venturi tube at flue gas temperatures typical of electric power stations.

For practical purposes, sometimes we must know the dependence of the mean droplet diameter directly on the velocity of gases and the throat of the Venturi tube. This dependence is shown in Fig. 5.

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